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13. ABSTRACT (Maximum 200 words)

A low-index waveguide of lens shape is embedded in a high-index $Ga_{.72}Al_{.28}$/ $Ga_{.59}Al_{.41}As$ host waveguide with anti-reflection layer incorporated at the lens boundaries to reduce reflections. An improvement factor of 1.25 in the throughput efficiency of the lens is achieved by the inclusion of AR layer. At an f-number of 1.8 and a wavelength of 1.152 um, a focal spot size of 2.1 um and a sidelobe level of -13 dB were measured. The angular field of view measured in the host waveguide is 11°. A quadri-level photomasking technique was developed for the fabrication of the new lens structure. This technique can be applied to various integrated optics structures where reflection reduction is required between low-index and high-index waveguide regions.

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A NEW GUIDED WAVE LENS STRUCTURE AND ITS APPLICATION

INTRODUCTION

Guided-wave lens is one of the key components in integrated optics [1]-[5]. It is used for collimation, imaging, and Fourier transformation [3]-[5]. Many lens structures have been reported for integrated optics. These include the Luneburg [6], [7], geodesic [8], [9], Fresnel [10]-[12], grating [13], [14], and aspheric lenses [15]-[17]. Except the geodesic lens, the lens function of the other structures is achieved by the differing refractive indices of the lens and the surrounding regions. Consequently, the most important parameter of producing a high performance lens is an adequate difference of the refractive indices [18], [19]. In view of this, we recently developed a new lens structure of a lens-shaped low-index waveguide embedded in a high-index host waveguide as shown in Fig. 1 [20]. Using GaAs/$Ga_{.93}Al_{.07}As$ host waveguide with low-index waveguide lens region of glass/SiO_2, an index difference of 1.89 is acnieved at a wavelength of 1.152 μm. An f/2 lens with 4 mm focal length demonstrated a FWHM spot size of 2.44 μm, a field of view exceeding 10°, and a throughput efficiency of 45%. The lens has low chromatic aberration and high polarization independence.

Along with the large index difference between the embedded lens region and the host waveguide, it comes significant reflection at the lens boundaries. This reduces the lens throughput efficiency. In this project, we carried out the design and implementation of antireflection (AR) layer at the interfaces between the lens region and the host waveguide. The concept is similar to AR coating in bulk optics. However, due to the specific cavity structure, the fabrication of the AR layer in the new design is a challenge. A quadri-level photomasking technique was developed to fabricate both the embedded lens waveguide and the AR layer. $Ga_{.72}Al_{.28}As/Ga_{.59}Al_{.41}As$ host waveguide structure is used for

transparency at wavelength as short as .8 μm. Configuration, fabrication and measurement results of the lens with AR layer are presented.

LENS CONFIGURATION AND FABRICATION

Fig. 2a exhibits the cross-section of the lens with AR layer. The lens top view is the same as that shown in Fig. 1. The ideal cross-section structure is extremely difficult to produce. Thus, it is modified to the one shown in Fig. 2b. Fig. 7 displays the layout of the lenses. The radii of the input and output faces of the lens are 11.4 mm and 2.6 mm, respectively. The lens waist is .1 mm. The lens aperture is 2.2 mm and the focal length is 4 mm, giving an *f*-number of 1.8. In fabrication, a quadri-level photomasking composite was deposited on the $Ga_{.72}Al_{.28}As/Ga_{.59}Al_{.41}As$ host waveguide as shown in Fig. 4. The composite consists of PMMA, thermally hardened photoresist, Ti and soft photoresist layers. The outer photoresist was exposed and developed to form the bi-concave lens shape opening. Reactive ion etching (RIE) process was used to etch away the remaining composite and etch into the host waveguide by 3.5 μm to produce a lens shape cavity. The etching gas was Cl_2 for Ti and host waveguide, and O_2 for hard photoresist and PMMA, respectively. In the above RIE process, the soft photoresist and Ti layers in the region other than the lens cavity were also etched away. In the host waveguide, $Ga_{.72}Al_{.28}As$ guiding layer is 1.7 μm thick and $Ga_{.59}Al_{.41}As$ cladding layer is 2.7 μm. The effective index of refraction for TE_0 mode in the waveguide at 1.152 μm wavelength is 3.29.

To produce a low-index waveguide, a thin adhesion layer and 2.05 μm of SiO_2 layer were deposited on the bottom surface of the cavity by e-beam evaporation. These materials also stayed on the hard photoresist layer which remained after the RIE process and on the sidewalls of the cavity. The PMMA underneath the hard photoresist layer was dissolved to lift off the SiO_2 on the top surface and on the sidewalls. Thus, only the

bottom surface of the cavity has SiO_2. Fig 5 shows the SEM image of the cavity after the lift-off process. TiO_2 was then deposited on the sidewalls of the cavity as AR layer. During deposition, the TiO_2 also stayed on the SiO_2 at the bottom of the cavity, forming a portion of the guiding layer. The AR layer has an index of 2.2 and a thickness of .13 μm. To complete the low-index waveguide, 1.7 μm thick of Corning 7059 glass was sputtered for the main guiding layer. The effective index of refraction of the low-index waveguide for TE_0 mode is 1.547. Since the lens region has lower index of refraction, a bi-concave shape results in a positive lens.

EXPERIMENTAL RESULTS

To measure the lens performances, a 1.152 μm HeNe laser beam was endfire coupled to the host waveguide as depicted in Fig. 6. TE_0 mode was excited first. The guided wave was focused by the lens onto the output facet where the focal plane was located. Using a microscope objective, the intensity distribution at the focal plane was projected onto an IR TV camera or a beamscan profiler. Fig. 3 displays the profile of the focal spot when a 2.2 mm on-axis beam was used. It is seen that the spot size at half power is 2.1 μm and the sidelobe level is -13 dB below the mainlobe. When TM_0 mode was excited, the spot size increases only to 2.5 μm, indicating high polarization independence. At f/1.8, the diffraction limited spot size without spherical aberration is calculated to be .56 μm [20]. The spot size including spherical aberration is 1.4 μm. Thus, the measured spot size is limited by the spherical aberration and the objective resolution. Notice that an f-number of 1.8 is equivalent to a numerical aperture of .91 because the focus is located in the host waveguide where the effective index is 3.29.

Next the throughput efficiency was measured. It was obtained by comparing the optical power of the focal spot on the output facet to the power transmitted through the

host waveguide without lens. For the lens with AR layer, the efficiency measured is 61% and the theoretical one based on Eqs. (1) and (3) of [20] is 82%. Lens without AR layer was also produced in the same fabrication steps. For the lens without AR layer, the measured efficiency is 49% and the calculated value is 62%. The ratio of calculated efficiency with AR layer to that without AR layer is equal to 82 / 62 = 1.32 This is the theoretical improvement factor by the inclusion of AR layer. We see that the measured improvement factor of 61 / 49 = 1.25 is very close to the theoretical value.

Off-axis performance was studied. When the angle between the incident beam in the host waveguide and the optical axis was increased to 5.5 degrees, the intensity of the focal spot was reduced by 50% due to higher reflectance of oblique incidence. The spot size did not increase significantly at this angle, however, because of large index difference between the host and lens waveguide, which results in a Petzval surface of small curvature. An angular field of view of 11° in the host waveguide is thus achieved.

SUMMARY

In summary, we have incorporated anti-reflection (AR) layer in the waveguide lens structure reported previously in [20]. The AR layer was inserted between the glass/SiO_2 low-index waveguide lens region and the $Ga_{.72}Al_{.28}As/Ga_{.59}Al_{.41}As$ host waveguide. The measured throughput efficiency of the lens increases from 49% for lens without AR layer to 61% for lens with AR layer, giving an improvement factor of 1.25. The lens with AR layer was fabricated using a quadri-level photomasking technique. This technique can be applied to various integrated optics structures where reflection reduction is required between low-index and high-index waveguide regions.

LIST OF PUBLICATIONS

Tzu J. Su and Chin C. Lee, "An Embedded Waveguide Lens with Anti-reflection Layer," submitted to IEEE Photonics Tech. Letters, Sept. 1993.

LIST OF PARTICIPATING SCIENTIFIC PERSONNEL

Tzu J. Su, MS, Spring 1992

Ph.D., Continuing

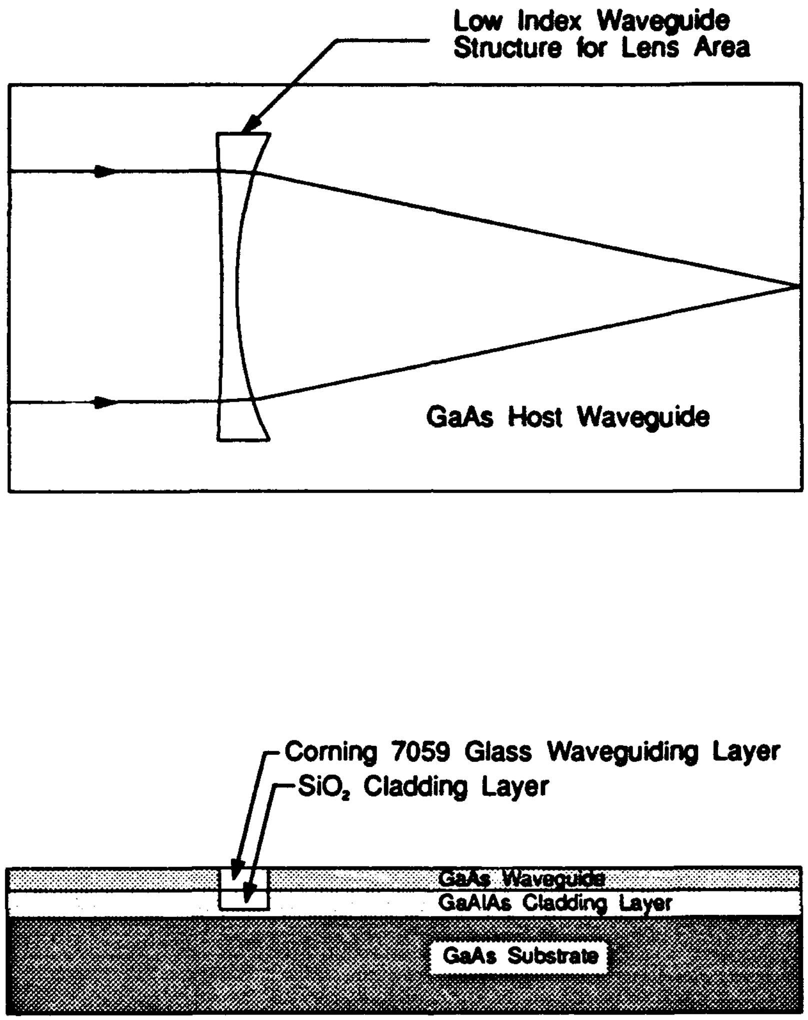
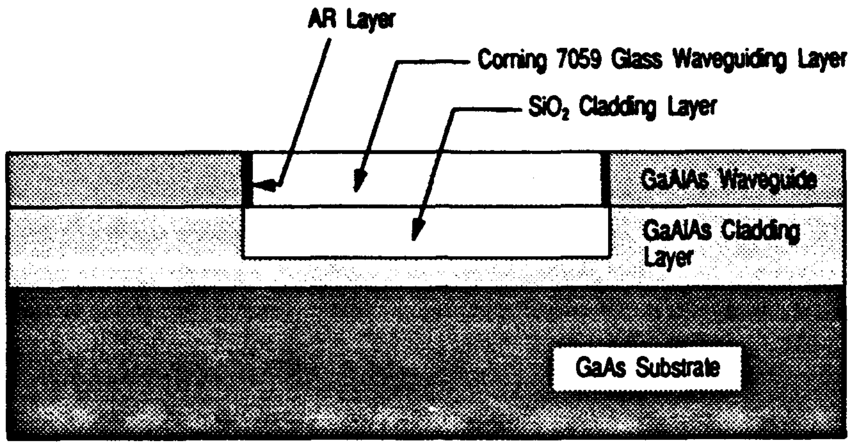
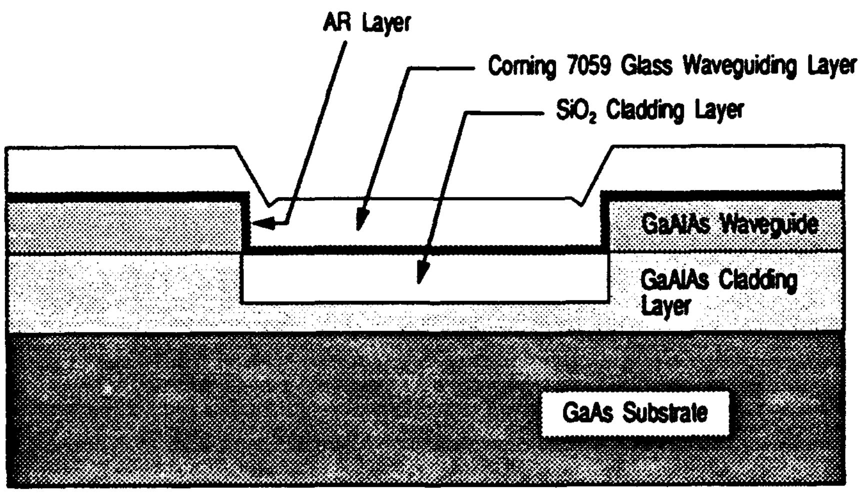


Fig. 1 Top and side views of the embedded waveguide lens structure.



(a)



(b)

Fig. 2 (a) Cross-section of the ideal lens with AR layer. (b) Cross-section of the modified lens with AR layer.

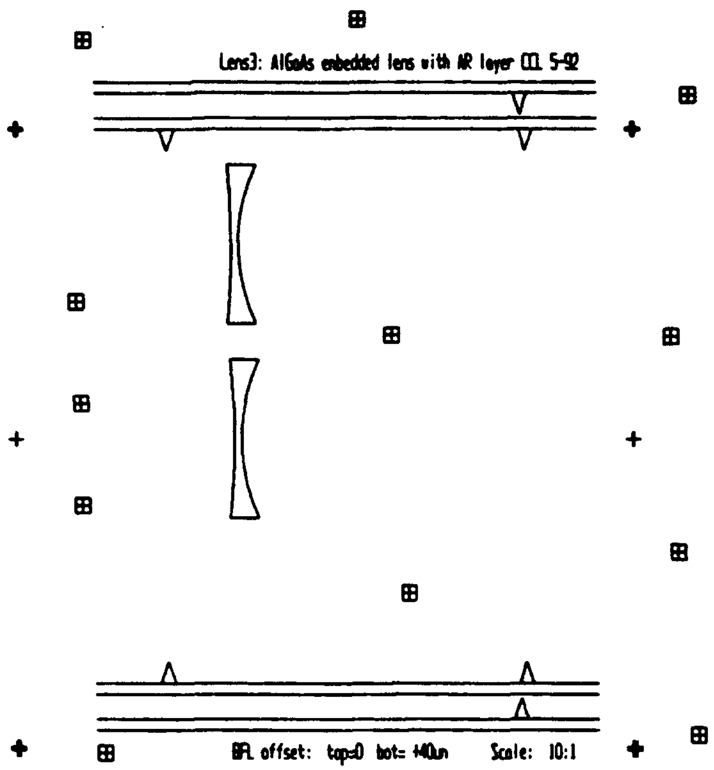


Fig. 3 Layout of the embedded lenses.

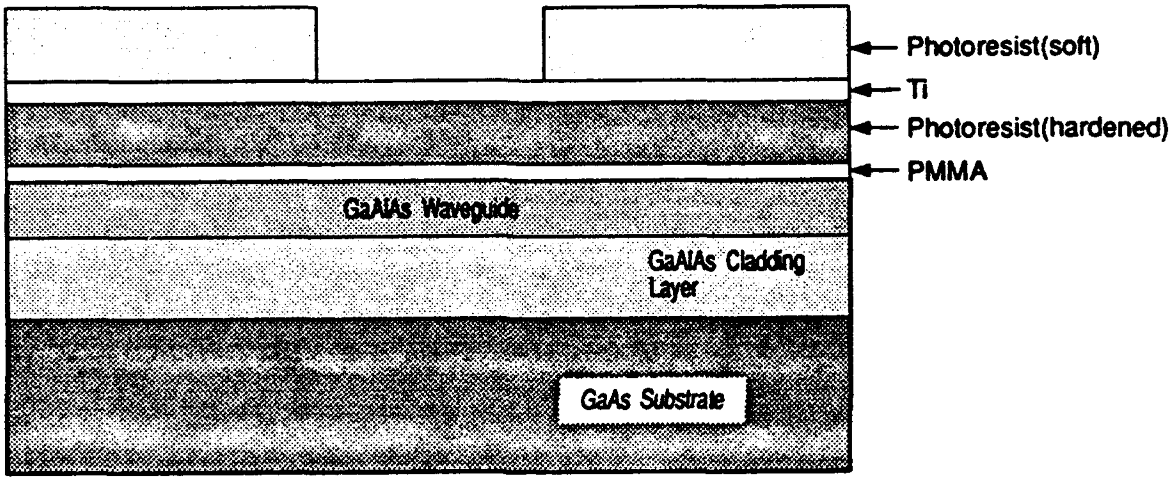


Fig. 4 Quadri-level photomasking composite for RIE.

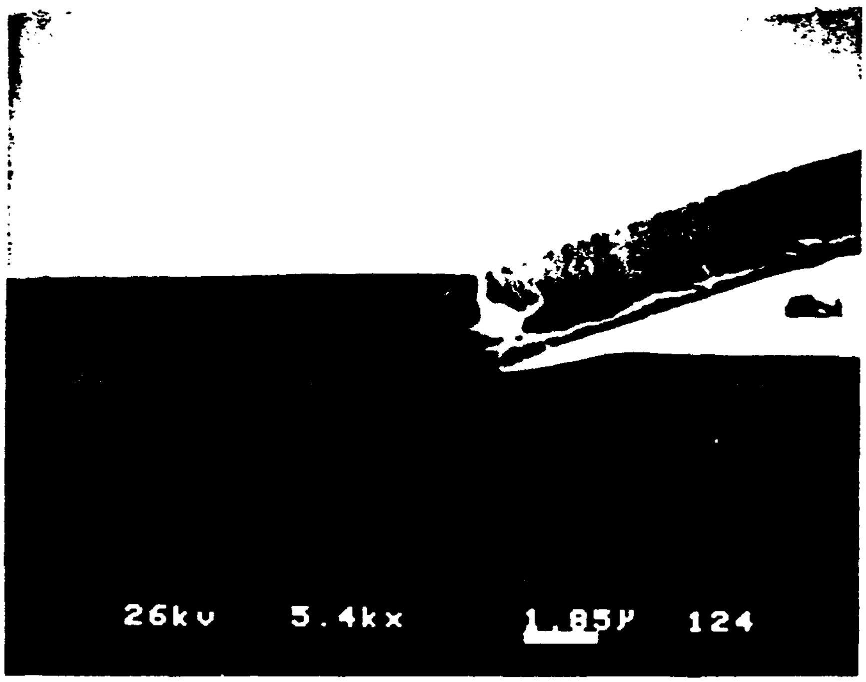


Fig. 5 The SEM image of the cavity after lift-off process.

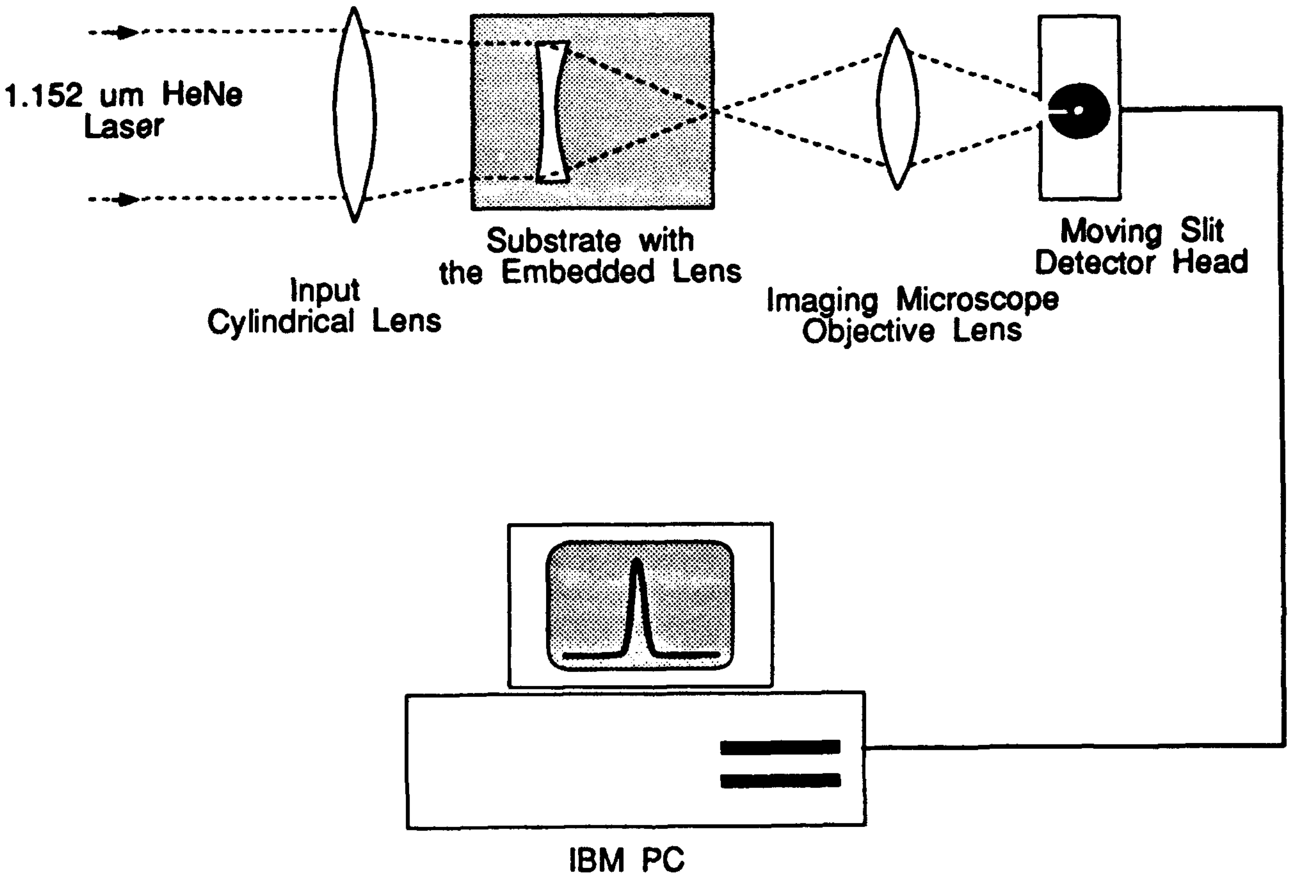


Fig. 6 Optical setup for the performance measurement of the embedded lens.

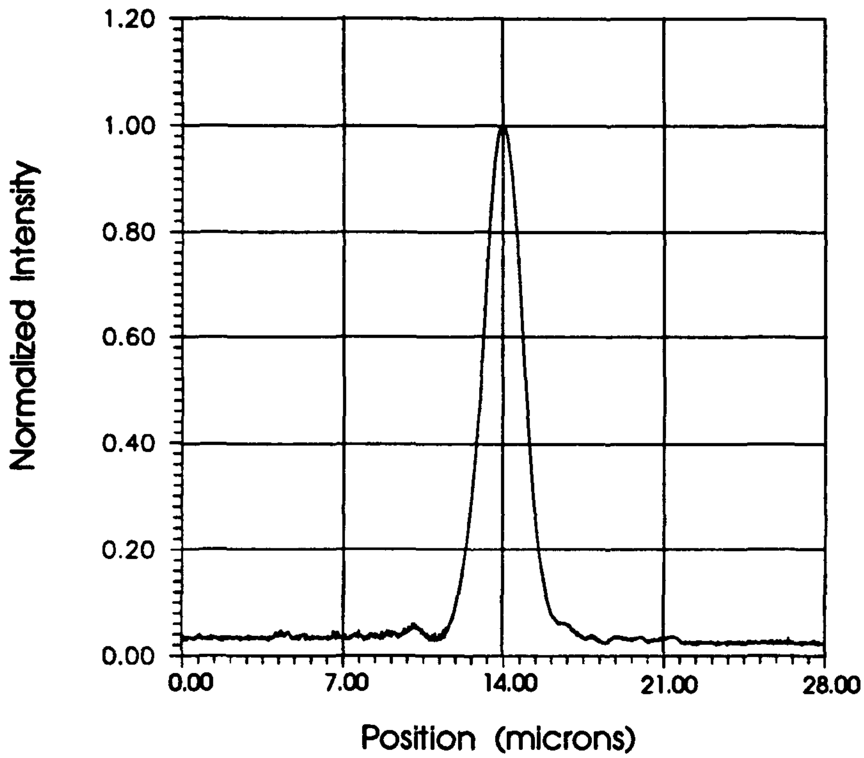


Fig. 7 Intensity profile of the focal spot obtained with a 1.152 μm 2.2mm on-axis beam. The f-number is 1.8 and the resulting half-intensity spot size is 2.1 μm.

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